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Procedia Engineering 87 (2014) 847 – 850

Procedia Engineering

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EUROSENSORS 2014, the XXVIII edition of the conference series

Thermally pulsed metal oxide gas sensor combined with a colorimetric gas sensor for the detection of trace gases

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Abstract

A low-cost gas sensor array with low-power consumption consisting of two chemical sensors based on different principles and a smart pattern recognition technique is presented. The sensor array consists of a thermally pulsed metal oxide gas sensor combined with an optical sensor based on the colorimetric principle. Metal oxide gas sensors suffer from inadequate selectivity and colorimetric sensors from slow response times. The aim of the presented work is to compensate these drawbacks through intelligent data fusion using an artificial neural network. It can be shown that the disadvantages of the two types of sensors can be compensated by the data fusion. The proof of principle is demonstrated by trace gas measurements with carbon monoxide, nitrogen dioxide and ammonia.

Peer-review under responsibility of the scientific committee of Eurosensors 2014

Keywords: gas sensor; sensor array; data fusion; artificial neural network

1. Introduction

The use of inexpensive sensors with low-power consumption is becoming increasingly important in a variety of applications. Especially for battery-operated systems, e.g. fire detectors, systems for ambient air monitoring or distributed sensor networks, energy self-sufficient gas sensors are required. There are even efforts to implement gas sensors in handheld devices like mobile phones. Often metal oxide gas sensors (MOX sensor) are in use. They are

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Peer-review under responsibility of the scientific committee of Eurosensors 2014
doi:10.1016/j.proeng.2014.11.286

cost effective, robust and sensitive, but with the lack of selectivity. For this reason we combine a thermally pulsed MOX sensor with a colorimetric sensor by intelligent data fusion. For data fusion, an artificial neural network – a variation of a recurrent network [4] with higher order neurons – is used.

2. Gas sensor array

The presented sensor array consists of two chemical sensors based on different measurement principles. One of these sensors is a thermally pulsed semiconductor metal oxide gas sensor. This kind of sensor is very inexpensive, very sensitive and robust. A disadvantage of this sensor type is the relatively high energy consumption, because the metal oxide layer of the sensor must be heated up to an operating temperature around 350°C. One way of reducing the energy consumption is the pulsed mode, in which the sensor is switched on only for a short time [5]. This energy-saving mode is applied in this work; the sensor is switched on only for 50ms. A further disadvantage of semiconductor gas sensors is the lack of selectivity. These sensors respond to a variety of gases, thus it is difficult to make an accurate statement about which gas was detected. Our approach is based on the fact that the reaction of the sensor to the gas is different depending on the operating temperature, so for further signal processing the entire heating and cooling process is evaluated. Nevertheless, a separation of the gases is very difficult, so another measurement method, a colorimetric gas sensor, is still used to increase the selectivity.

A sensitive layer of the colorimetric sensor changes its color during gas exposure very selectively towards the target gas [1-3]. Fig. 1 shows a scheme of the measurement principle. A LED irradiates three photodiodes, on which the colorimetric layers were directly deposited, with three sensitive layers selective to different gases. The intensity of light on the photodiodes depends on the concentration of the target gas. The used colorimetric materials are slow in their reaction to the target gas compared to MOX sensors. Therefore we evaluate the immediate signal change in the early absorption phase instead of the equilibrium.

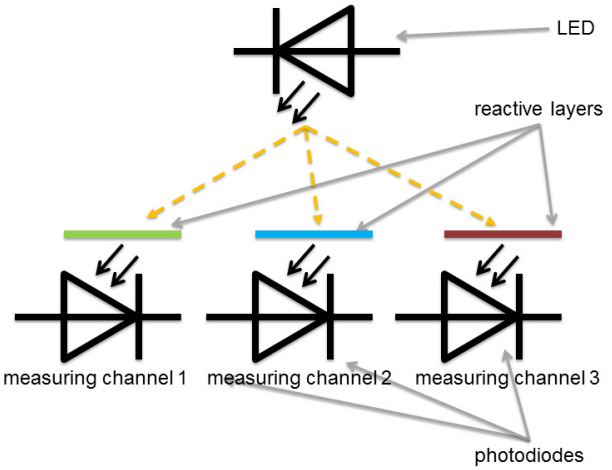

Fig. 1. : Set-up of the optical colorimetric sensor. The sensitive layers on the photodiodes change their color due to a gas reaction. A LED irradiates the photodiodes.

Fig. 2 shows a measurement with the two chemical gas sensors. We investigated three gases: carbon monoxide (CO), nitrogen dioxide (NO_2) and ammonia (NH_3). The diagram (a) shows the reaction of the MOX sensor to the test gases. The sensor responds to all gases and, depending on whether these are oxidizing or reducing, with an increasing or decreasing signal. The diagram (b) shows the reaction of the colorimetric gas sensor with a sensitive layer to ammonia (tetrabromine-phenolsulfonphthalein in ethyl cellulose). There is a slow sensor response only to ammonia but no response to other gases.

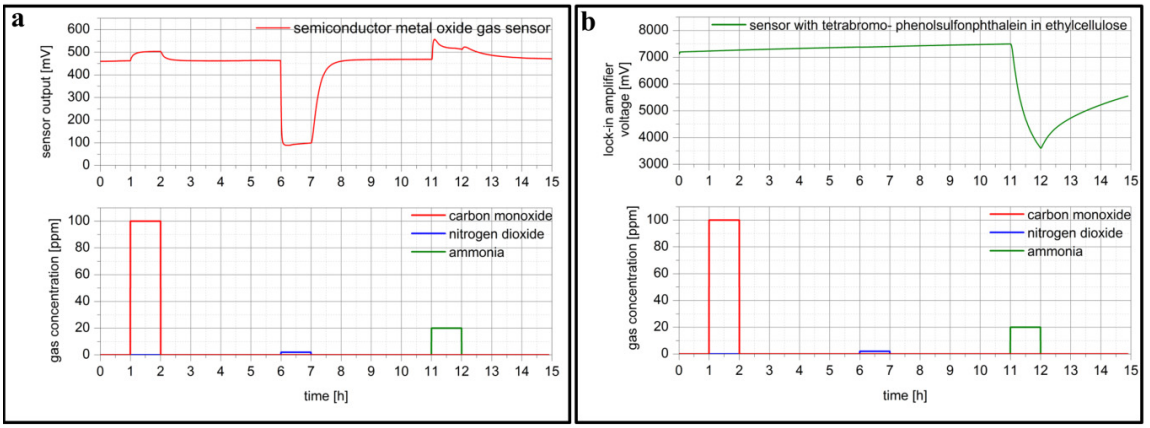

Fig. 2. (a) Gas measurement using a metal oxide gas sensor exposed to 100ppm CO, 2 ppm NO_2 and 20 ppm NH_3; (b) Colorimetric gas sensor exposed to 100ppm CO, 2 ppm NO_2 and 20 ppm NH_3

3. Signal processing steps and signal fusion

Fig. 3 shows the signal processing steps and the signal fusion to calculate the gas concentration. The artificial neural network called “Context Layered Recurrent Sigma-Pi Neural Network” (CLLRSPNN) receives the complete heating and cooling down process of the semiconductor gas sensor and the first derivation of the lock-in output signal from the colorimetric gas sensor. The network is trained to output the respective gas concentrations from the incoming sensor signals. The artificial neural network has an input layer, two hidden layers, an output layer and a context layer. The context layer provides the possibility to evaluate the dynamic sensor signal of the gas sensors. The neurons of the second hidden layer, sigma-pi neurons, are neurons of higher order. The neural network in this configuration provides the ability the fusion of the two very different gas sensors.

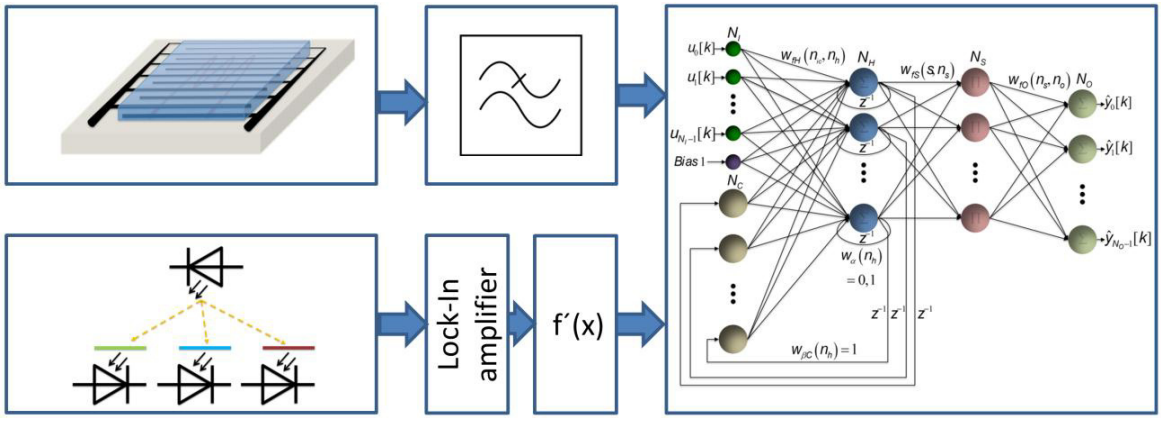

Fig. 3. Signal processing steps and sensor data fusion of the metal oxide gas sensor and the colorimetric gas sensor.

(1)

4. Results

Fig. 4 show the fused results of the two different gas sensors with the trained neural network to NH_3, NO_2 and CO during exposure to all three gases. The sensor array with the colorimetric sensor for NH_3 shows the highest selectivity and sensitivity. The main reason for that is the remarkable color change of the dye (tetrabromine-phenolsulfonphthalein in ethyl cellulose). Due to the cross-sensitivities to NO_2, the detection of CO using a color dye (rhodium complex in ethyl cellulose), becomes more difficult. Nevertheless, a significant increase of selectivity is observed.

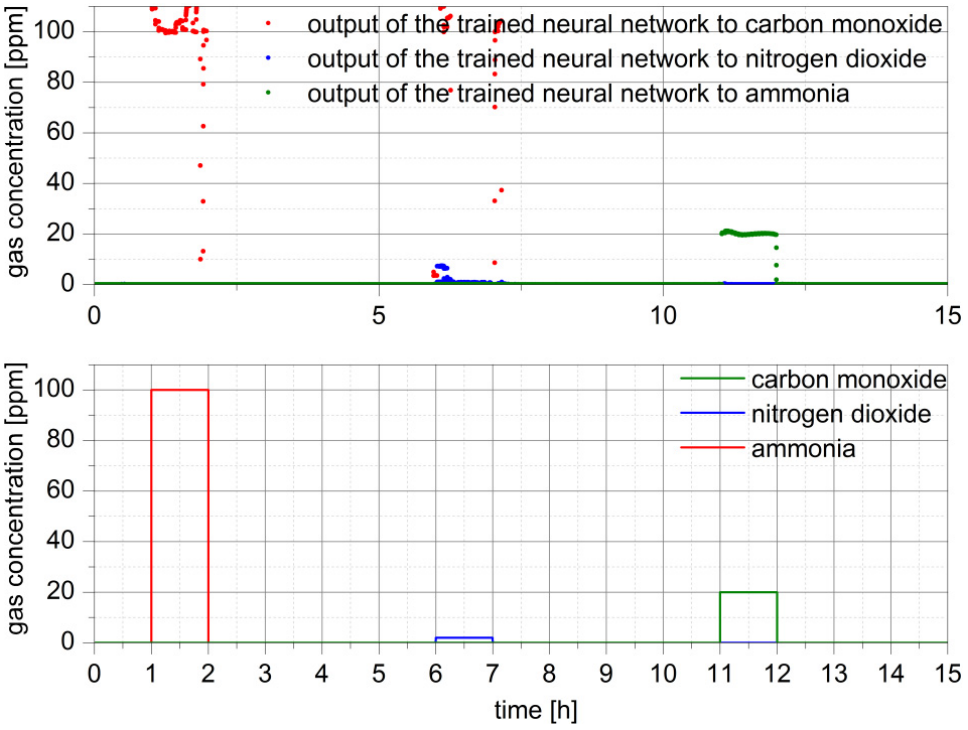

Fig. 4. Gas measurement with the fused sensors. (a) output signals of the system versus time. The artificial neural network was trained to CO (red), NO_2 (blue) and NH_3 (green); (b) exposure to test gases during the experiment (CO, NO_2 and NH_3)

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